UNSTABLE SLOPE MANAGEMENT

WASHINGTON STATE

STEVE LOWELL AND PAT MORIN

Throughout Washington State a wide variety of unstable slopes impact highway facilities. Failure of these unstable slopes not only puts the traveling public at risk, but also has an adverse effect on regional commerce when closing the facilities is required for any length of time. Prior to 1993 the Washington State Department of Transportation (WSDOT) responded to unstable slope failures primarily in a reactive mode, using maintenance forces or emergency contracts to clean up and stabilize slopes. In the early 1990s, however, WSDOT began to explore ways of addressing unstable slope issues in a more proactive and rational manner. Early estimates indicated that a large number of unstable slopes existed statewide, that the potential for traffic disruption posed by these slopes was quite high, and that the cost to mitigate the problem exceeded $300 million.

During the development of its budget for 19951997, WSDOT initiated a new way of programming projects in its highway construction program. This new approach involves prioritizing and programming projects according to the extent to which they address deficiencies whose resolution will accomplish system service objectives. The intent of this new approach is to provide WSDOT executives and appointed and elected state transportation policy decision makers the information they need to make difficult investment choices in the highway construction program. The investment choices from which they select are developed through long-range policy and system planning processes with strong public involvement.

The system service objectives were defined through a planning process focused on what Washington State must accomplish to have a multimodal transportation system capable of meeting the needs of its citizens and business community into the 21st century One of the service objectives is preserving the highway infrastructure in a cost-effective manner to protect the public investment in the system. An action strategy for this highway preservation service objective is to stabilize known unstable slopes on a statewide basis.

Development of Unstable Slope Management System

The development of WSDOT's Unstable Slope Management System (USMS) began in fall 1993, when implementation of the new programming approach was initiated. At that time, there was no fully implemented unstable slope management system in place in the United States that WSDOT could use as a model. Accordingly, WSDOT developed a comprehensive management system that would be used to (a) rationally evaluate all unstable slopes, (b) perform early project scoping and cost estimation, (c) conduct benefit-cost analysis of unstable slopes, and (d) prioritize the mitigation of known unstable slopes according to the expected benefits. Development and management of the technical aspects of the statewide USMS became the responsibility of WSDOT's Geotechnical Branch.

The first major task in the development of the USMS was to compile an accurate list of known unstable slopes along WSDOT's 7,000-mile highway system. This task was assigned to WSDOT's six regional maintenance divisions, since they knew where the unstable slopes were located, and could also provide information concerning the type(s) of instability, frequency of failure, and estimated annual maintenance costs.

To achieve consistency in the information collected by individual maintenance superintendents, a common set of characteristics was developed. These characteristics include the location of the slope

Steve *Lowell* is Chief Engineering Geologist, *Geotechnical* Branch, *Washington* State Department of *Transportation;* Put Morin is Priority Development and Management Engineer, Office of *Program Management, WSDOT.*

(based on state route mileposts), whether the slope is right or left of the centerline, types of slope instabilities, defining frequency of failure, and dollar ranges for estimated annual maintenance costs associated with mitigating the slope instabilities. This information was compiled into a master list of unstable slopes, which served as the basis for the statewide unstable slope inventory

Rating of Unstable Slopes

Washington State is a diverse region with widely varying terrain, geologic conditions, and associated slope instabilities. To prioritize individual slopes within the statewide inventory, the slopes must be rated in a systematic manner on the basis of consistent and measurable criteria. To that end, WSDOT developed a numerical slope rating system that can be used to evaluate risks to the highway facility (see Table 1).

Although the use of a matrix-based numerical rating system in evaluating rockfall-related slope stability is not unique, the WSDOT system is distinctive in that both soil and rockslope instabilities are included within the same matrix, and the ratings are consistent for both types of unstable slopes. Additionally, many rockfall-related numerical rating systems tend to focus on characterizing the geologic and geotechnical aspects of the slope instability WSDOT's system addresses the failure mode of the slope in only one rating category, with the remaining categories dedicated to establishing risk to the highway facility Points, ranging from 3 to **81,** are assigned to 11 risk categories, and the exponential scoring system quickly distinguishes increasing importance or hazard potential. Total points can range from a low of 33 to a high of 89 1. The total point value for an individual slope is generally correlated with the level of overall risk to the highway facility It is important to note that this numerical rating system is not a predictive model; in other words, a higher-rated slope will not necessarily fail before a lower-rated slope.

Early in the inventory process it was anticipated that the number of unstable slopes statewide could be quite large. Thus an interim step using a preliminary rating system would be needed to assign the unstable slopes to broad, more manageable, categories. This preliminary system used three subjective categories to evaluate the potential of an unstable slope site to experience a failure that would impact

TABLE 1 Rating System for Unstable Slopes

Criterion	Points = 3	Points = 9	Points = 27	Points = 81
Problem Type: Soil	Cut, or Fill Slope Erosion	Settlement or Piping	Slow-Moving Landslides	Rapid Landslides or Debris Flows
Problem Type: Rock	Minor Rockfall, Good Catchment	Moderate Rockfall, Fair Catchment	Major Rockfall, Limited Catchment	Major Rockfall, No Catchment
Average Daily Traffic	<5,000	5,000–20,000	20,000–40,000	>40,000
Decision Site Distance	Adequate	Moderate	Limited	Very Limited
Impact of Failure on Roadway	<50 ft	50–200 ft	200–500 ft	>500 ft
Roadway Impedance	Shoulder Only	1/2 Roadway	3/4 Roadway	Full Roadway
Average Vehicle Risk	<25% of the Time	25–50% of the Time	50–75% of the Time	>100% of the Time
Pavement Damage	Minor—Not Noticeable	Moderate—Driver Must Slow	Severe—Driver Must Stop	Extreme—Not Traversible
Failure Frequency	No Failures in Last 5 Years	One Failure in Last 5 Years	One Failure Each Year	More Than One Failure Each Year
Annual Maintenance Costs	<$5,000 per Year	$5,000–$10,000 per Year	$10,000–$50,000 per Year	>$50,000 per Year
Economic Factor	No Detours Required	Short Detours <3 Miles	Long Detours >3 Miles	Sole Access, No Detours
Accidents in Last 10 Years	1	2–3	4–5	>5

the highway facility: Category A (high potential), Category B (moderate potential), and Category C (low potential). This interim step facilitated the numerical ratings by making it possible to focus only on slopes with a high potential to impact the highway system. Since the majority of the unstable slopes currently in the inventory have now been rated numerically, this interim step has been discontinued.

Database of Unstable Slopes

Since the inception of the USMS, unstable slopes have been reviewed by regional maintenance and materials offices every 2 years before the next biennium's budget cycle. Doing so provides an opportunity to update existing unstable slopes and add new ones to the statewide inventory

WSDOT's unstable slope inventory currently contains more than 2,500 slopes and is maintained in a centralized Microsoft Access™ database that allows for quick manipulation, sorting, grouping, and custom reporting of the information. In addition to the numerical ratings discussed above, the database contains information related to the highway facility, such as highway functional class, roadway type, average daily traffic, and WSDOT region. The current inventory includes unstable slopes in three main categories: slope erosion, landslide, and rockfall. The largest single category is rockfall, which comprises approximately 36 percent of the slope problems encountered by WSDOT; those problems generally occur in the heavily traveled mountainous highway corridors between western and eastern Washington. The second-largest category is slope erosion (30 percent), followed by landslide (25 percent). Although slope erosion appears to be a rather prevalent problem, experience has shown that these slopes generally do not pose a serious threat to WSDOT's highway system.

Maximizing Return on Investment

One of the primary goals of priority programming is to address transportation deficiencies or needs in those areas that offer the highest return on the limited investment dollars available. Early in the development of the USMS, it was recognized that a worst-first approach by total inventory was probably not appropriate from this perspective. For example, an unstable slope with a high numerical rating could be located along a highway with very low traffic volume or one used on a seasonal basis. Correcting an unstable slope in such a situation might not provide the largest benefit for the dollars expended.

To ensure, to the extent possible, the highest return on the transportation dollars spent, the unstable slopes in the inventory were grouped on the basis of highway functional class. Unstable slopes along Interstate facilities and principal arterials are being mitigated first, followed by those on

On-slope stabilization of an unstable rock slope using a bencher drill to install rock bolts and dowels in north central Washington State.

lower-volume facilities. Within each highway functional class, the slopes are ranked in descending numerical order, so that the highest-risk slopes within that class are considered first.

Project Scoping and Cost Estimation

A key advantage offered by the USMS is the ability to conduct early project scoping and cost estimation. Once a ranked list of unstable slopes has been developed, a first cut at the program for the next biennium is made on the basis of the anticipated funding level. This first-cut list undergoes a field review by senior-level geotechnical staff from WSDOT's Geotechnical Branch.

The field review serves several purposes. First, it provides a quality and consistency check on the numerical rating of the slope. Each rating category is reviewed in detail, and the numerical ratings are adjusted as deemed necessary Second, the problem associated with the unstable slope is defined in detail, and enough field information is gathered so that conceptual slope-mitigation recommendations can be developed. A detailed problem statement, the conceptual mitigation recommendations, and estimating factors are provided to the regional pro-, gram managers. Scoping estimates are then compiled by the regions. The regions take the information provided in the conceptual mitigation recommendations and add such project items as mobilization, traffic control, surfacing and paving, preliminary engineering, construction engineering, sales tax, and contingencies. Once the scoping estimates have been completed by the regions, they are returned to the Geotechnical Branch for benefit-cost analysis.

Construction of a rock shear key to stabilize an embankment affected by a landslide in southwest Washington State.

Determining the direct and indirect economic impacts of a slope failure along a highway facility can be very difficult and time-consuming, since partial or full closure of a highway facility can have far-reaching effects on both public and private entities. To illustrate the point, a recent landslide in southwest Washington closed a major east-west corridor for 9 days. WSDOT was required to construct a short detour alignment around the landslide, clean up landslide debris, and maintain a 20-mile temporary detour. In addition, a wood products mill had to shut down its operations, and the local school district had to make alternate transportation and classroom plans for its students since the landslide had cut the district in half. .The total direct and indirect economic impacts of this landslide amounted to millions of dollars just for the temporary short-term mitigation of the problem.

Instead of attempting to determine the precise economic impacts of slope failure on a highway facility, it was decided to use indicators of those impacts. The two most reliable and easily calculated economic impacts resulting from a slope failure along a highway facility are the cost associated with traffic delays and the annual maintenance costs, factored over the life of the program (20 years).

With regard to costs associated with traffic delays, several simplifying assumptions had to be made. First it was necessary to make some judgment as to how long typical delays would be should a slope fail. Experience indicated that in most cases, traffic would be disrupted for at least 24 hours after a slope failure. Another factor to be considered was the amount of the roadway that would be impacted, since this would have a bearing on traffic flow through the area. The numerical rating system includes roadway impedance as one of the rating criteria, and this information was used to develop reduction factors in the calculation of traffic delay costs. For example, if the roadway impedance rating category indicated that just the shoulder of the highway would be impacted, only 25 percent of the total calculated traffic delay cost was used. Conversely, if the roadway impedance rating indicated that all lanes of the highway facility would be impacted, the total traffic delay cost (100 percent) was used. Similar reduction factors were developed for other roadway impedance ratings.

Life-cycle maintenance costs are determined on the basis of estimated annual costs generated by

regional maintenance personnel. These estimates are then multiplied by the 20-year program life.

To determine benefit-cost for each site being considered, the above two indicators-traffic delays and maintenance costs-are compared with the cost of mitigating the unstable slope site. In special cases, the regions can consider other known and quantifiable economic impacts. These cases typically involve lower-volume highway facilities or high-cost slope mitigations where the ramifications of a slope failure can have severe and far-reaching economic impacts.

For example, a highway facility along the western coast of Washington is being actively eroded. Although the highway is a low-volume facility, it serves as a historical levee for 350 acres of commercial cranberry bogs. If this highway facility were to be breached by the erosion, a multimillion-dollar industry for the local community could be destroyed. Although the solution to the problem is very expensive, the direct cost of the mitigation is warranted in light of the indirect costs of a failure to the local community

The results of the benefit-cost analysis are used to form a prioritized list of unstable slopes for programming purposes. Because of funding limitations, only those unstable slopes that have a benefit-cost ratio of **1** or higher are considered for the unstable slope program. This prioritized list of unstable slopes is provided to the Highway Construction Program's Office of Program Management for further consideration and program development.

Funding and Project Management

While the USMS is being used to prepare a priority list for the unstable slope action strategy, similar processes are occurring for the other action strategies of WSDOT's Highway Construction Program. When all of the resulting prioritized lists have been received by the Office of Program Management, budget scenarios are prepared on the basis of anticipated revenues for the next budget cycle. These scenarios include summaries of the benefits and anticipated performance outcomes for each budget category so that WSDOT's Executive Budget Committee can make recommendations to the Department's Transportation Commission. The Commission can then make informed investment choices among the various categories of work.

The comparison of different budget scenarios is referred to as the tradeoff process. During this process, input from citizens and local government officials is solicited. Having reviewed this information, the Transportation Commission adopts a final budget proposal and forwards it to the Washington State Legislature as part of the biennial budget process. The legislature conducts additional public hearings on WSDOT's proposal and has the authority to modify the Department's request before passing a final transportation budget.

Once the highway construction budget has been passed by the Washington State Legislature, the biennial funding level for unstable slope work is known. Work then begins on developing final geotechnical recommendations based on detailed geotechnical site investigation and analysis. Final geotechnical recommendations, within the original scope of work developed during the programming phase, are provided to the regions so that contract plans and specifications can be developed. Once construction contracts have been awarded, the Geotechnical Branch provides on-site geotechnical support to the regions as needed to resolve problems that may arise during slope mitigation.

The funding level for the unstable slope action strategy has been set at $30 million per biennium for 10 bienniums (20 years). In the first biennium of the program (1995–1997), the program funding was approximately $8 million. In the 1997-1999 biennium, the funding level increased to $20 million. For 1999-2001, the recommended funding level is the full $30 million. The final funding level is dependent on available revenues, and on whether the Washington State Legislature decides to appropriate funding to the recommended level.